Ecosystem change and land-surface-cloud coupling

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Congress on Climate Change

8)Earth System Feedbacks and Carbon Sequestration

Copenhagen, March 10, 2009

Outline of Talk

- **Land-surface climate:**

  - surface & cloud processes

1) LBA data: Jaru forest & Rondonia pasture

2) Idealized equilibrium model:

   - forest and grassland; double CO_2
   - impact on BL cloud, NEE and temperature

Land surface climate

- **Highly coupled system: mean state + diurnal cycle**

  - **Surface processes**: evaporation & carbon exchange

  - **Atmospheric processes**: clouds & precipitation

- Clouds have radiative impact on SEB in both shortwave and longwave
- Precipitation affects RH and LCL
- Clouds are **"observable",** but are **poorly modeled**
- **Quantify by scaling shortwave cloud forcing as an "effective cloud albedo"**

“Cloud Albedo”

$$SW_{net} = SW_{down} - SW_{up} = (1-\alpha_{surf})(1-\alpha_{cloud})\, SW_{down}(clear)$$

- *surface albedo*

$$\alpha_{surf} = SW_{up} / SW_{down}$$

- *effective cloud albedo*
  - a **scaled surface short-wave cloud forcing, SWCF**

$$\alpha_{cloud} = -\, SWCF/SW_{down}(clear)$$

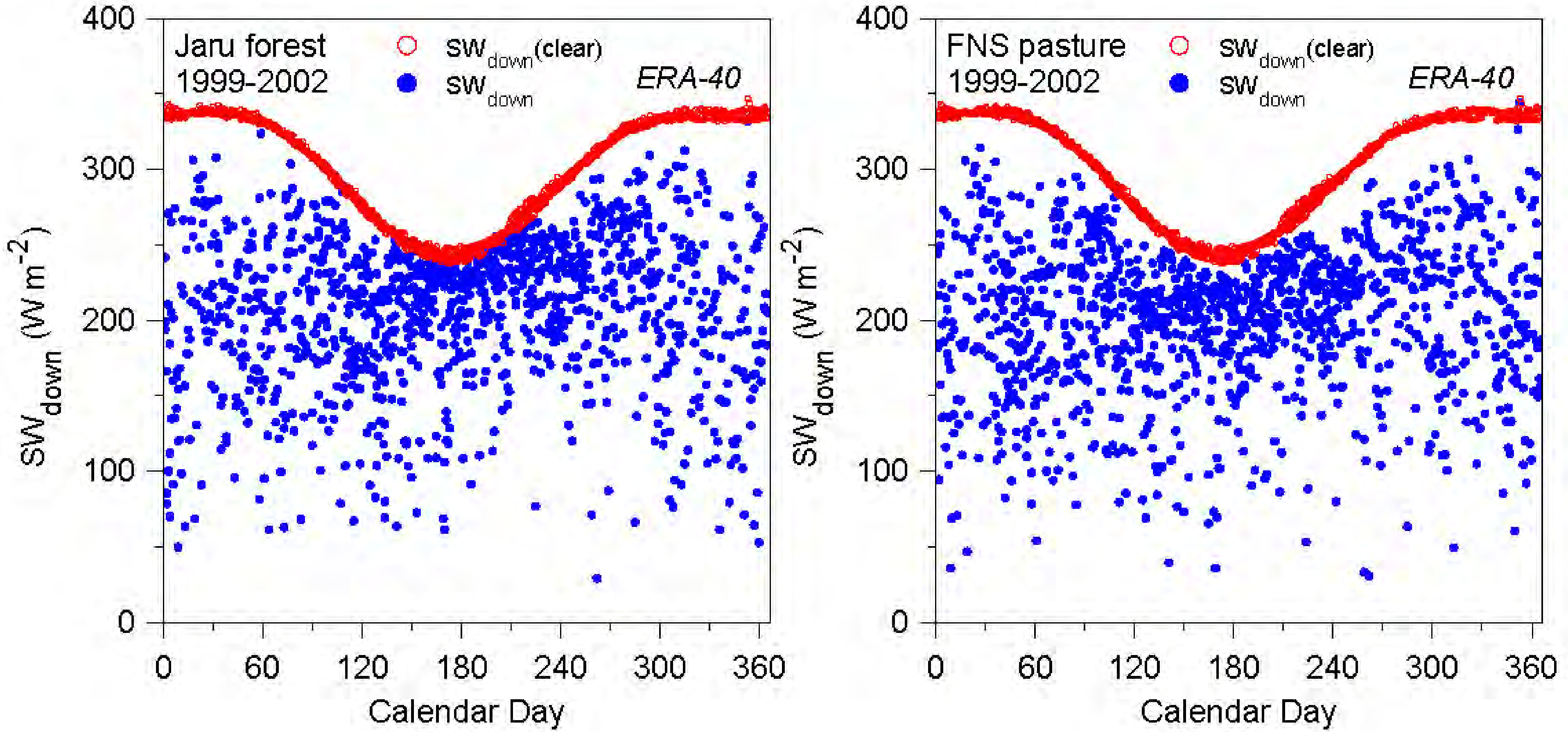
where

$$SWCF = SW_{down} - SW_{down}(clear)$$

[Betts and Viterbo, 2005; Betts, 2007]

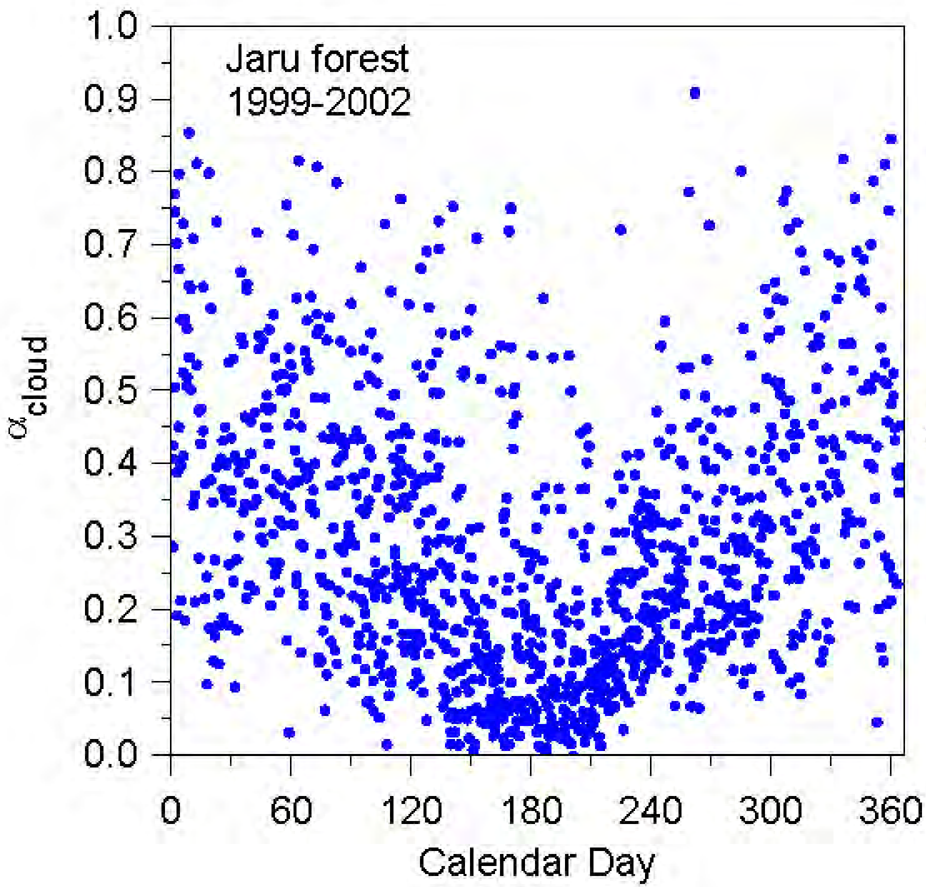
Jaru forest & Rondonia pasture : SWCF

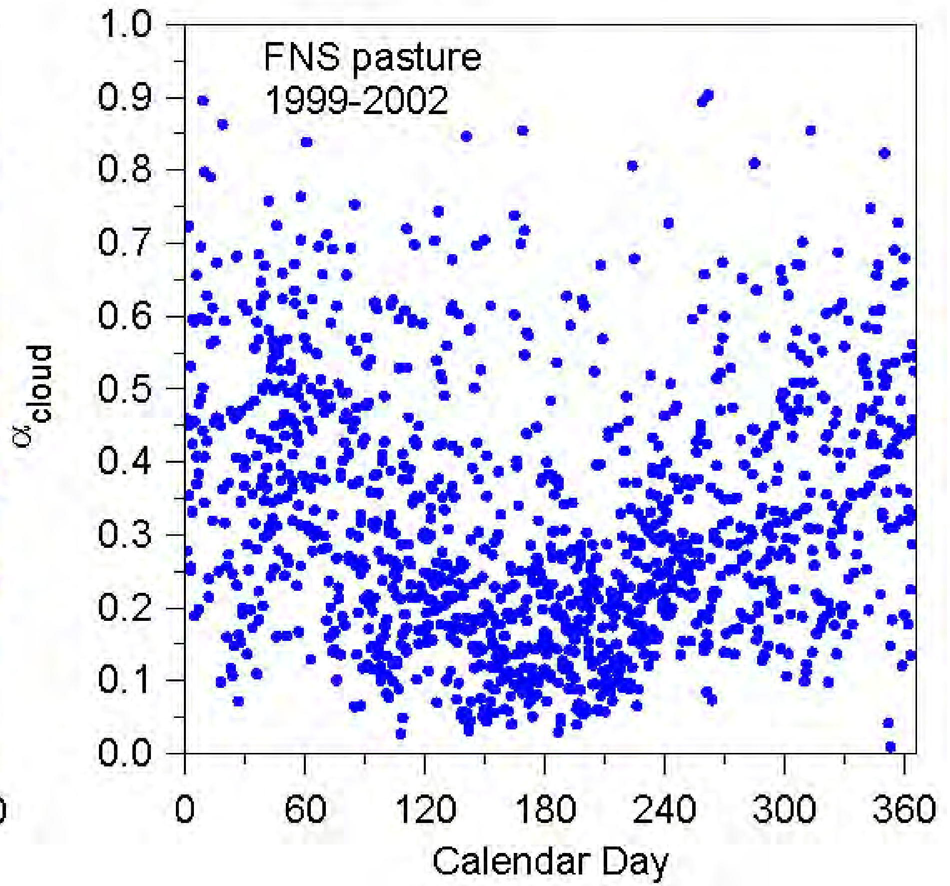
[daily mean data: von Randow et al 2004]



- More cloud over pasture in dry season
- Aerosol ‘gap’ in September burning season

Jaru forest & Rondonia pasture transformation to α_{cloud}





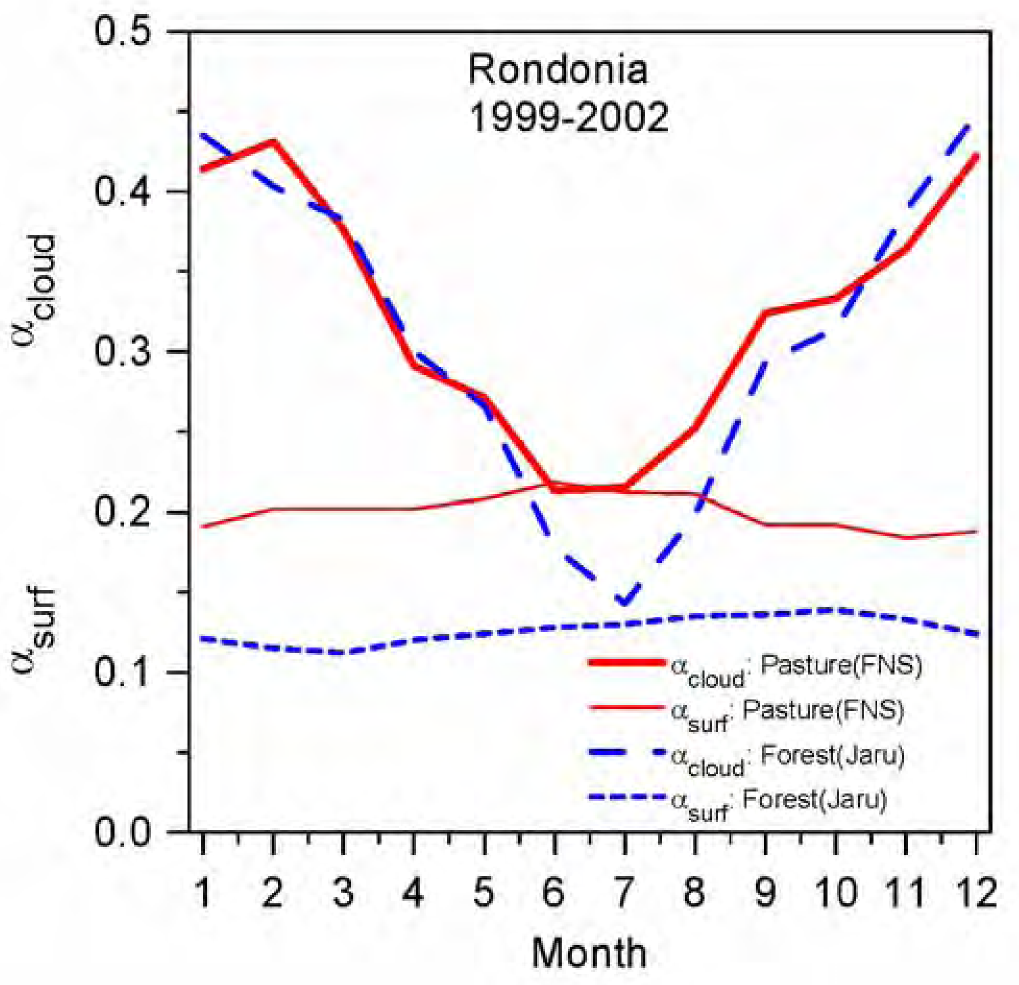
- More cloud over pasture in dry season

SW energy balance: forest and pasture

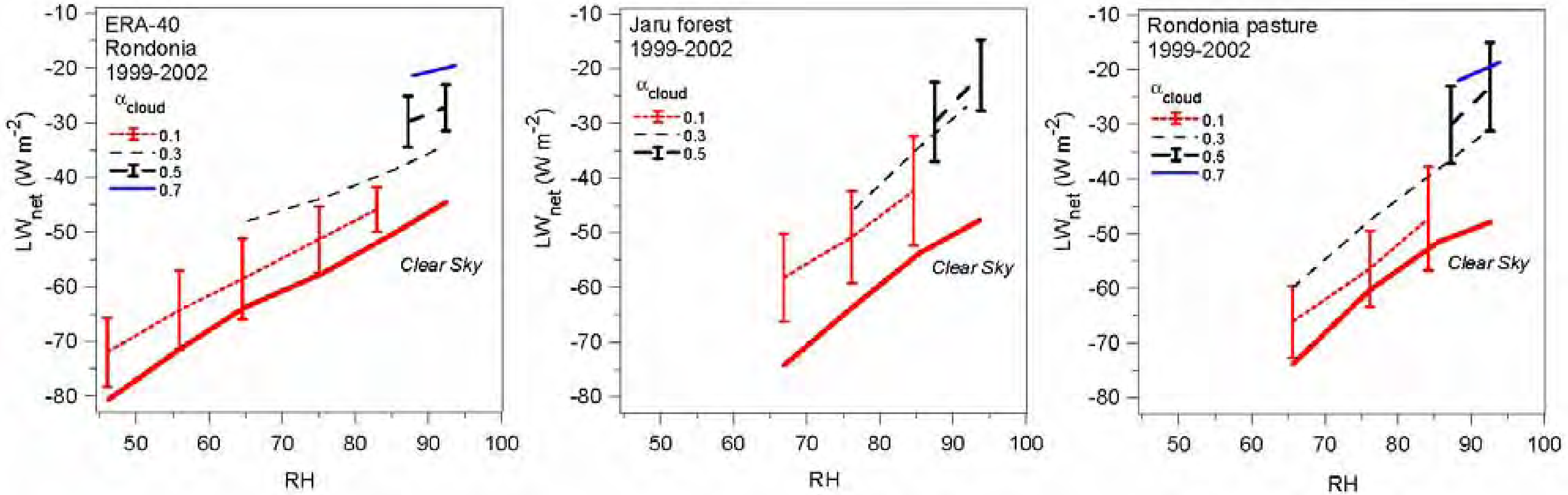
- Pasture in July, has

  +8% surface albedo

  +7% cloud albedo



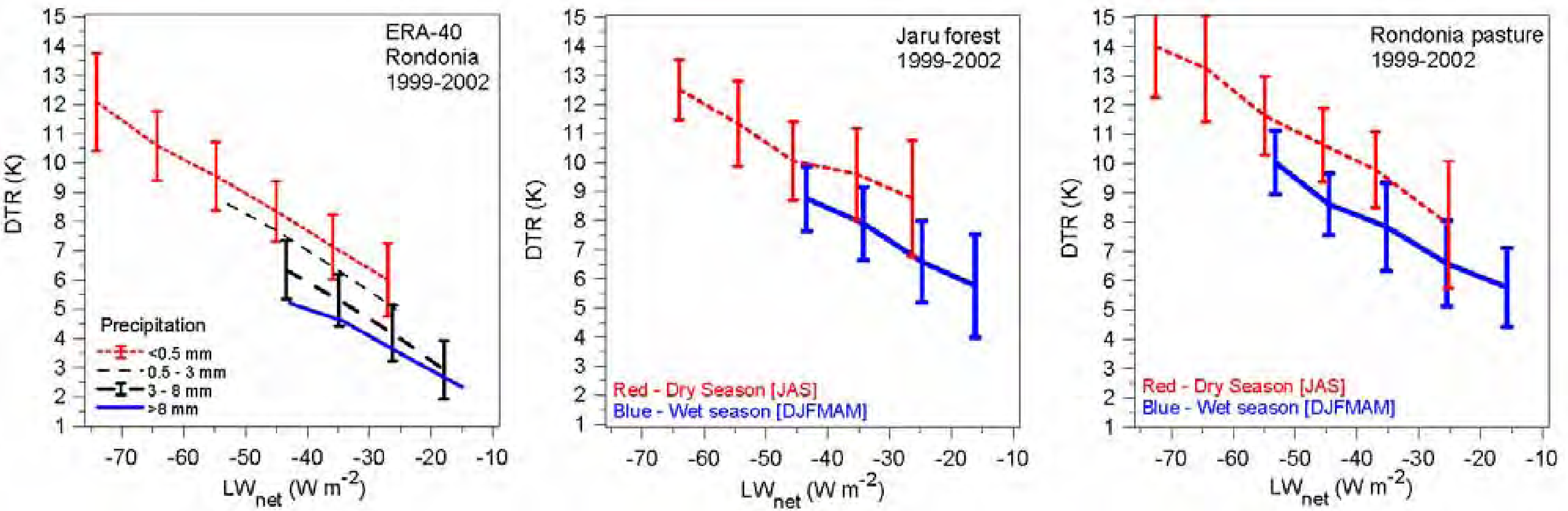
RH & cloud ⟶ LW_{net}



- ERA40 "point"; Jaru tower & Rondonia pasture
- Broadly similar [ERA-40 has 'drier' data]
- Humidity and cloud greenhouse effects

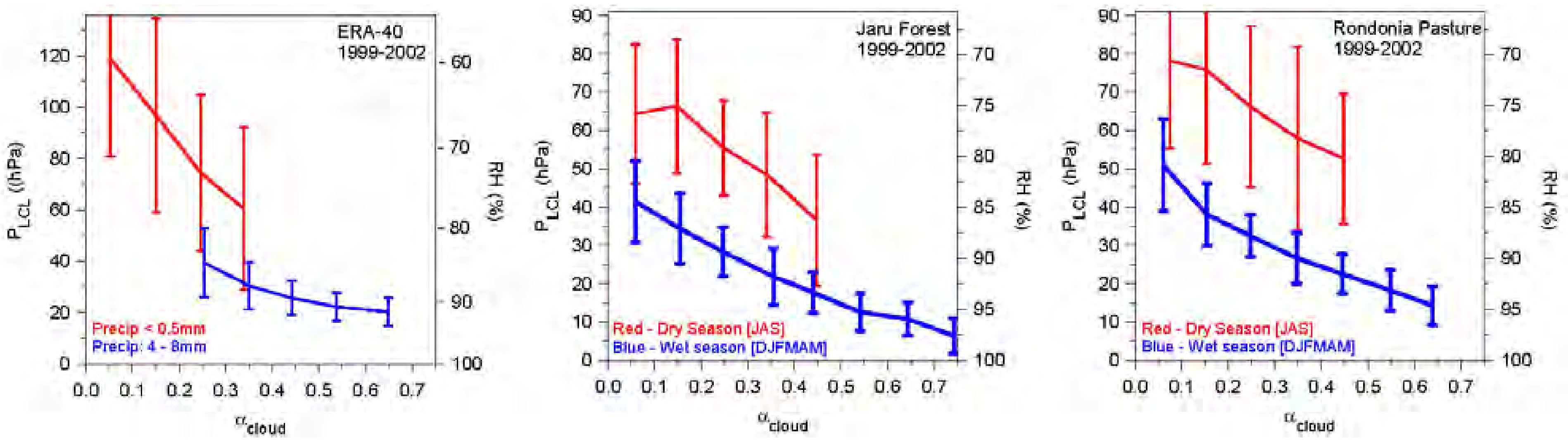
[ERA-40 calculations for clear sky]

$LW_{net} \rightarrow$ Diurnal Temp. Range



- **DTR quasi-linear with LW_{net}**
- ERA40 has steeper slope than observations
- Precipitation reduces DTR

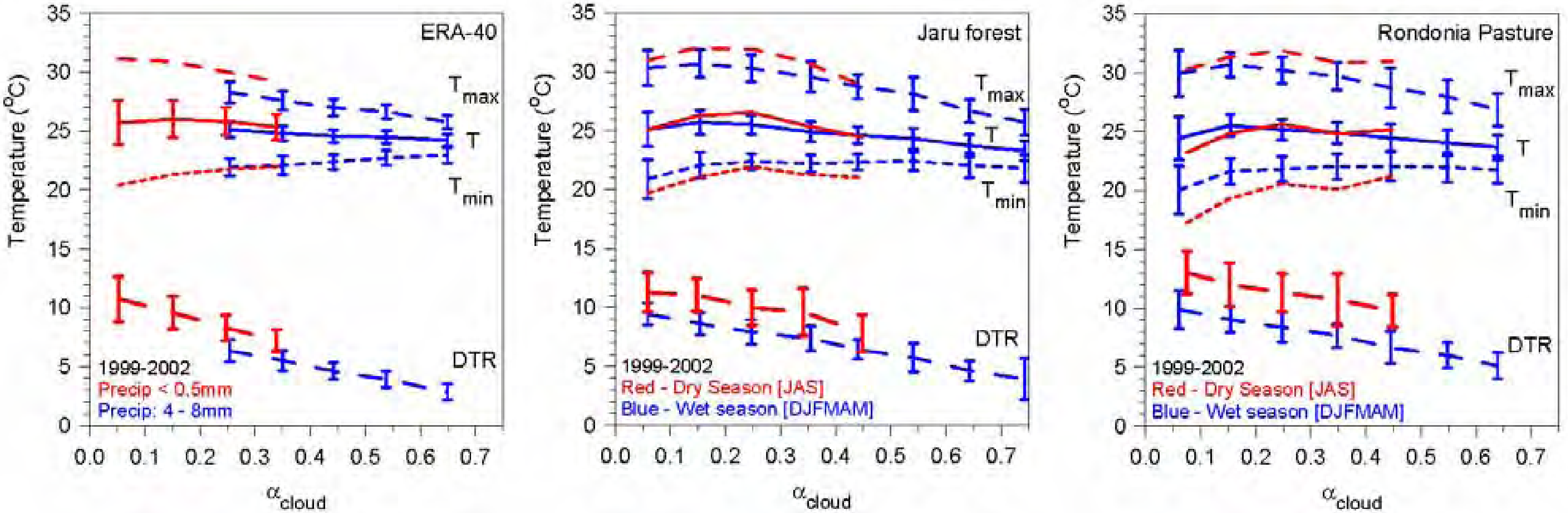
Organize by α_{cloud} [*observable*]



- **α_{cloud} , LCL & RH linked**
- Relation tight in rainy season;

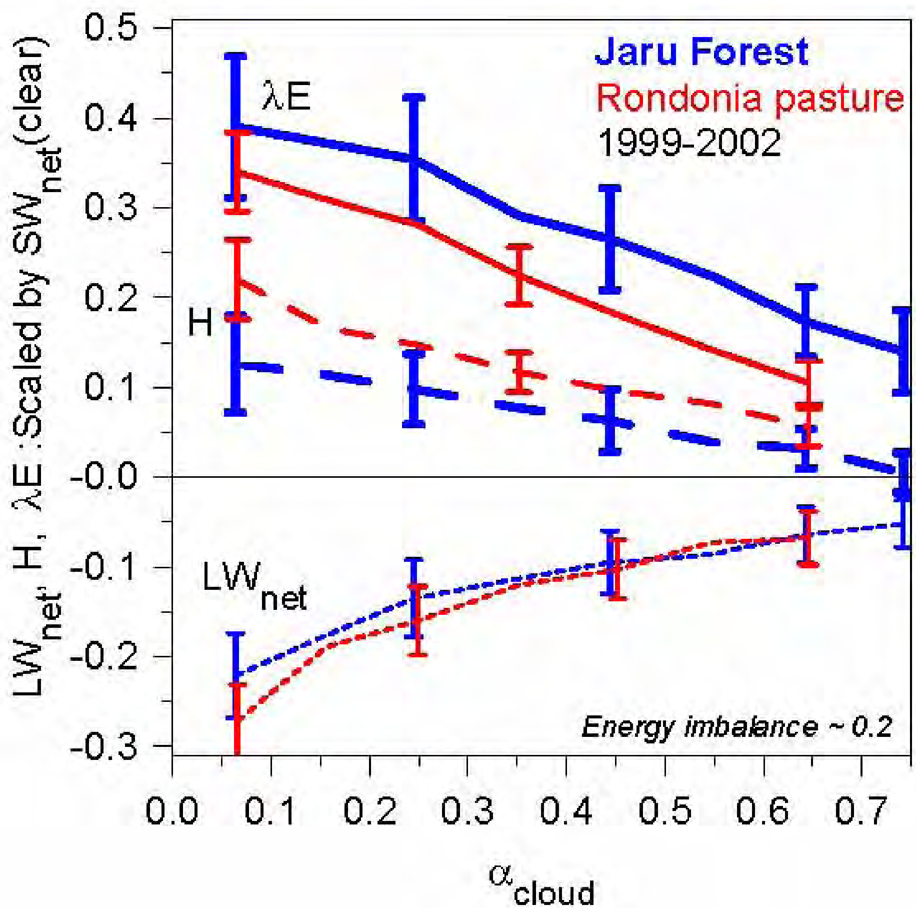
  - poor in dry season

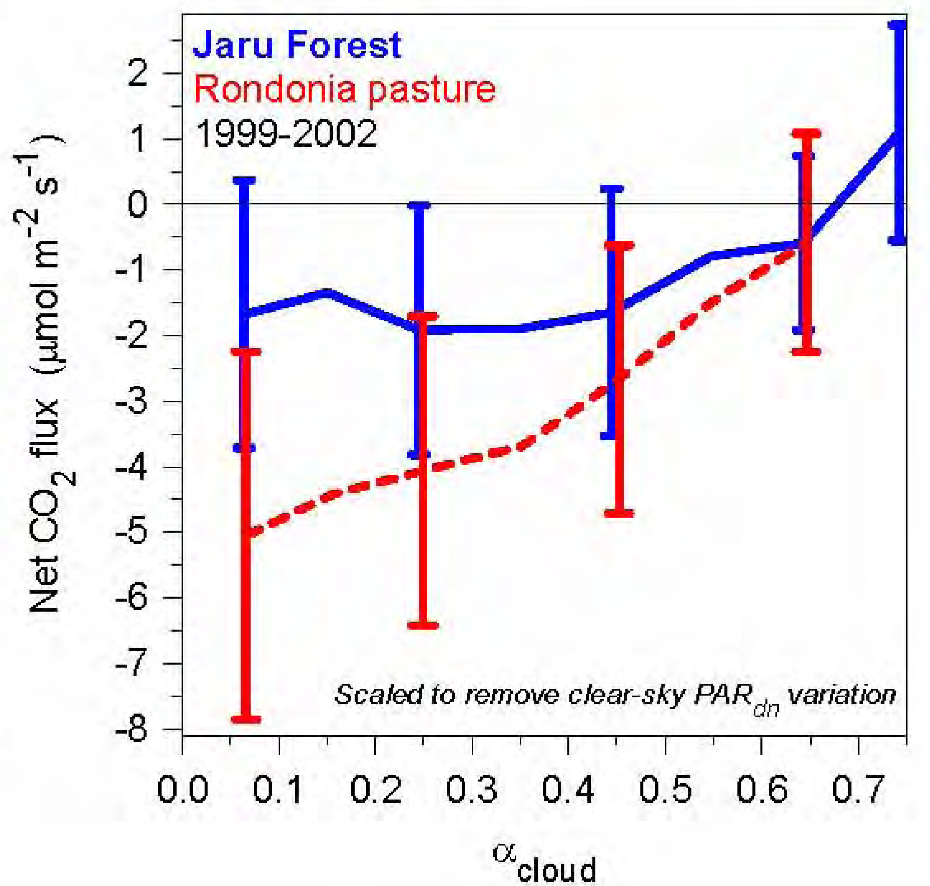
T_{max}, T_{min}, DTR and α_{cloud}



- **DTR and α_{cloud} linked**
- ERA-40: T_{max} decreases & T_{min} increases
- Data: Wet season: T_{max} decreases: T_{min} flat

Organize fluxes by α_{cloud}

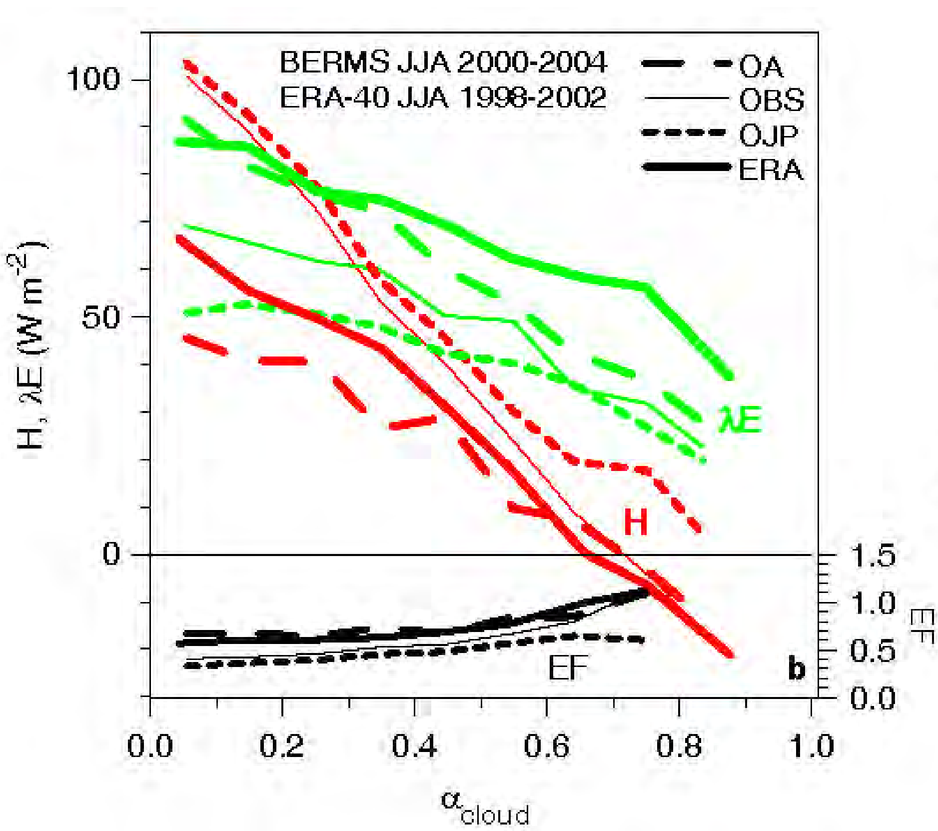


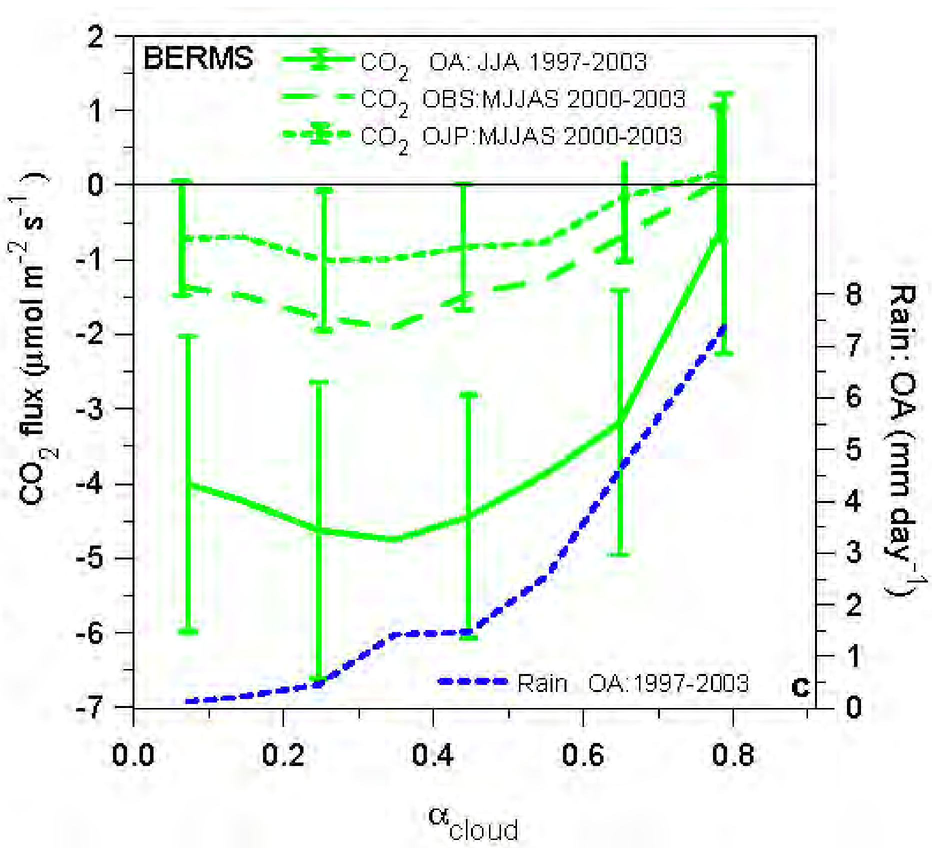


- Energy fluxes: quasi-linear
- Jaru forest carbon flux ‘flat’ at low $\boldsymbol{\alpha}_{\mathbf{cloud}}$

Summer Boreal forest: Saskatchewan

[Betts et al. 2006]





- Similar dependency on α_{cloud}
- Net CO_2 flux peaks at $\alpha_{cloud} \sim 0.35$

2) How will BL clouds and surface fluxes change in a warmer, high CO_2 world?

- Global and continental climate needs fully coupled system
- But vegetation-CO_2-λE-BL-cloud coupling may have significant errors

- Use **idealized model** to study coupled BL system as a function of soil water with specified mid-tropospheric forcing
  with SWCF and LWCF for BL clouds

Idealized Equilibrium BL model

- extension of

Betts, A. K., B. Helliker and J. Berry, 2004, Coupling between CO2, water vapor, temperature and radon and their fluxes in an idealized equilibrium boundary layer over land. J. Geophys. Res., 109, D18103, doi:10.1029/2003JD004420.

- Heat, radiation, moisture and CO_2 balanced ML-model with BL cloud forcing only

Model Structure

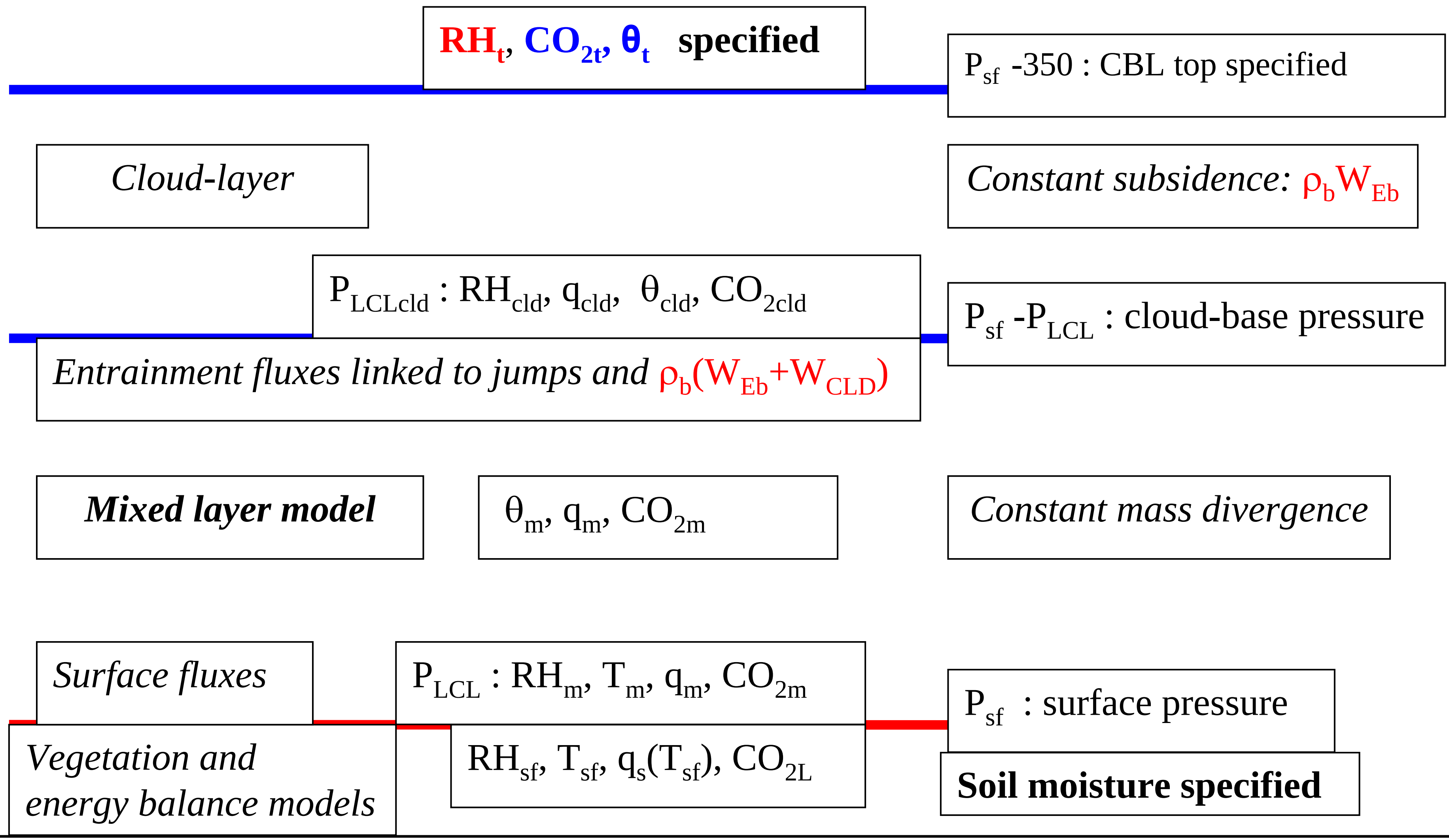
- External variables: soil moisture index; mid-tropospheric CO_2, RH, lapse-rate [coupled to moist adiabat]; Clear-sky SW_{net} radiation
- SW_{net}, LW_{net}, R_{net} and ML cooling coupled to cloud-base mass flux [‘cloud forcing’]
- Canopy photosynthesis model: *[Collatz et al, 1991]*

  [LAI, E_{veg}, Q_{10}] = [5, 6, 1.9] for forest *[Wisconsin]*

  = [3, 10, 2.1] for grassland

  - Temperature and soil water stress factors

Schematic


RH_t, CO_{2t}, θ_t specified
P_{sf} -350 : CBL top specified
Cloud-layer
Constant subsidence: $\rho_b W_{Eb}$
P_{LCLcld} : RH_{cld}, q_{cld}, θ_{cld}, CO_{2cld}
P_{sf} -P_{LCL} : cloud-base pressure
Entrainment fluxes linked to jumps and $\rho_b(W_{Eb}+W_{CLD})$
Mixed layer model
θ_m, q_m, CO_{2m}
Constant mass divergence
Surface fluxes
P_{LCL} : RH_m, T_m, q_m, CO_{2m}
P_{sf} : surface pressure
Vegetation and energy balance models
RH_{sf}, T_{sf}, $q_s(T_{sf})$, CO_{2L}
Soil moisture specified

Equilibrium solutions for forest and grassland

- Current climate: 380 ppm CO_2
- 2100 climate: 760 ppm CO_2

  & moist adiabat tropospheric reference T:
  tied to SST increase of +2K

  [very approx. A1B scenario; WG1, Ch 11]

ML equilibrium

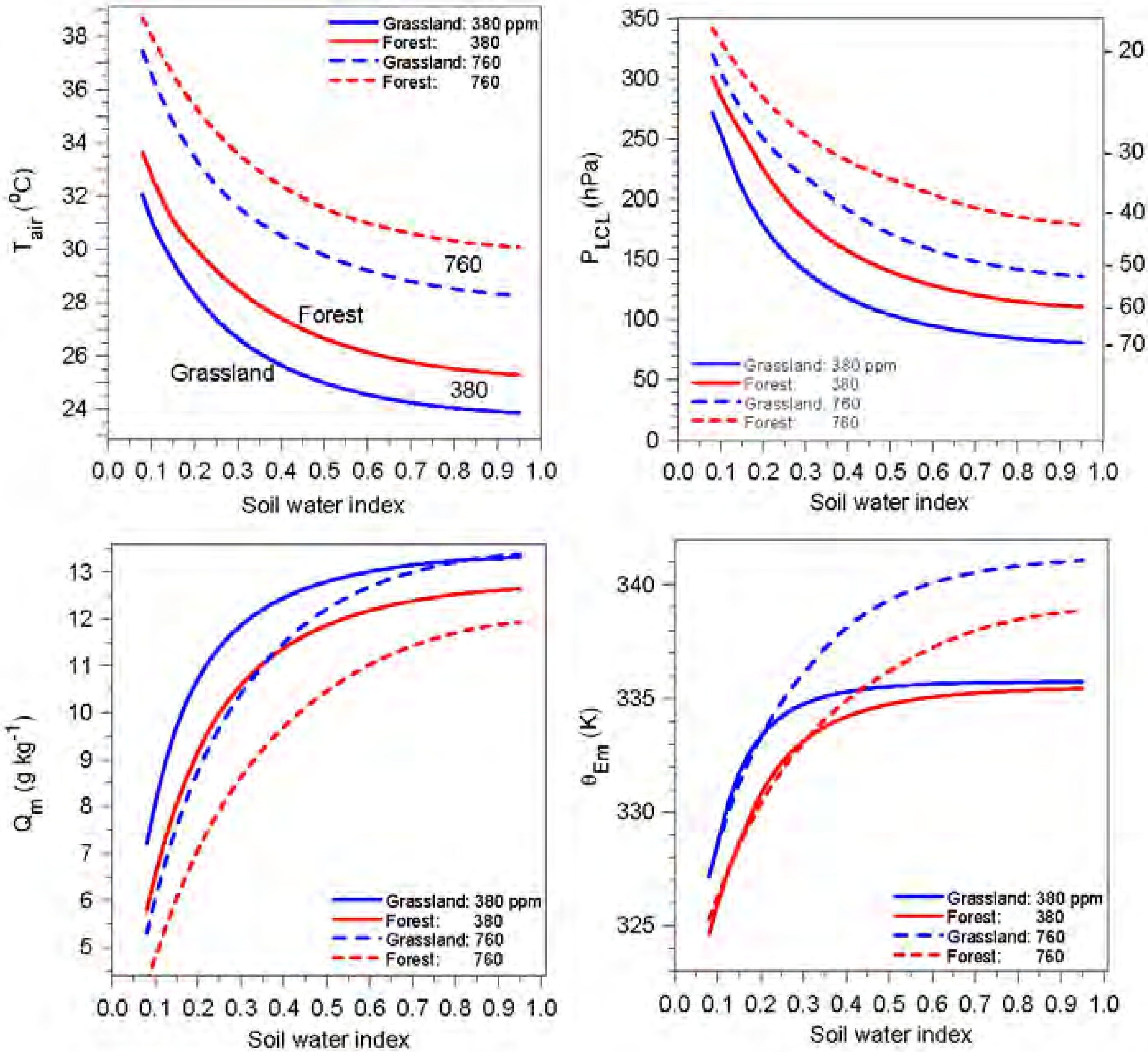
T_{air}

RH

P_{LCL}

Q

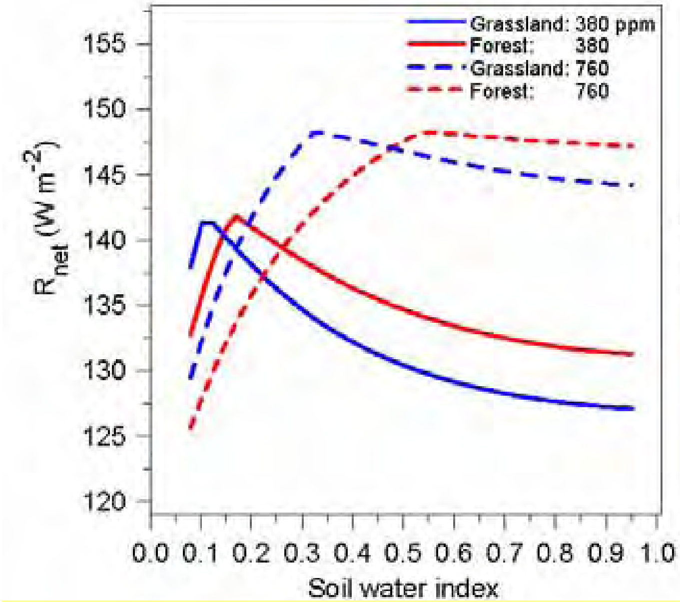
θ_E

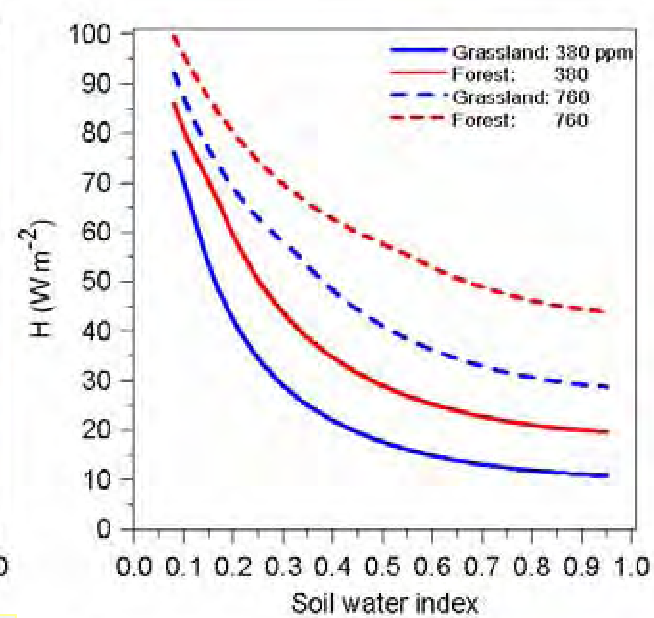


Soil water index

Surface energy fluxes

R_{net}





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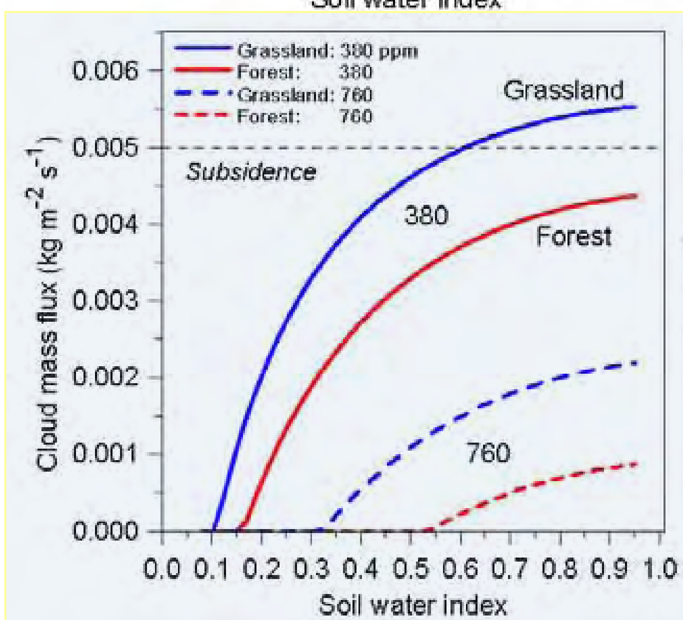
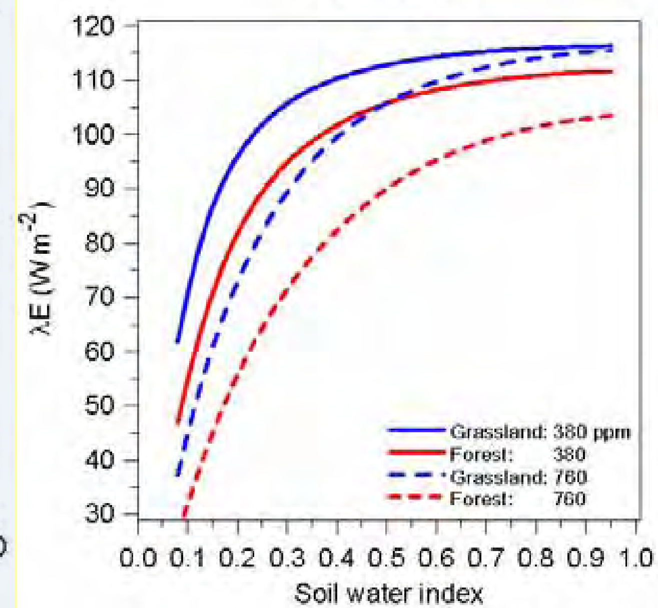
Cloud mass flux

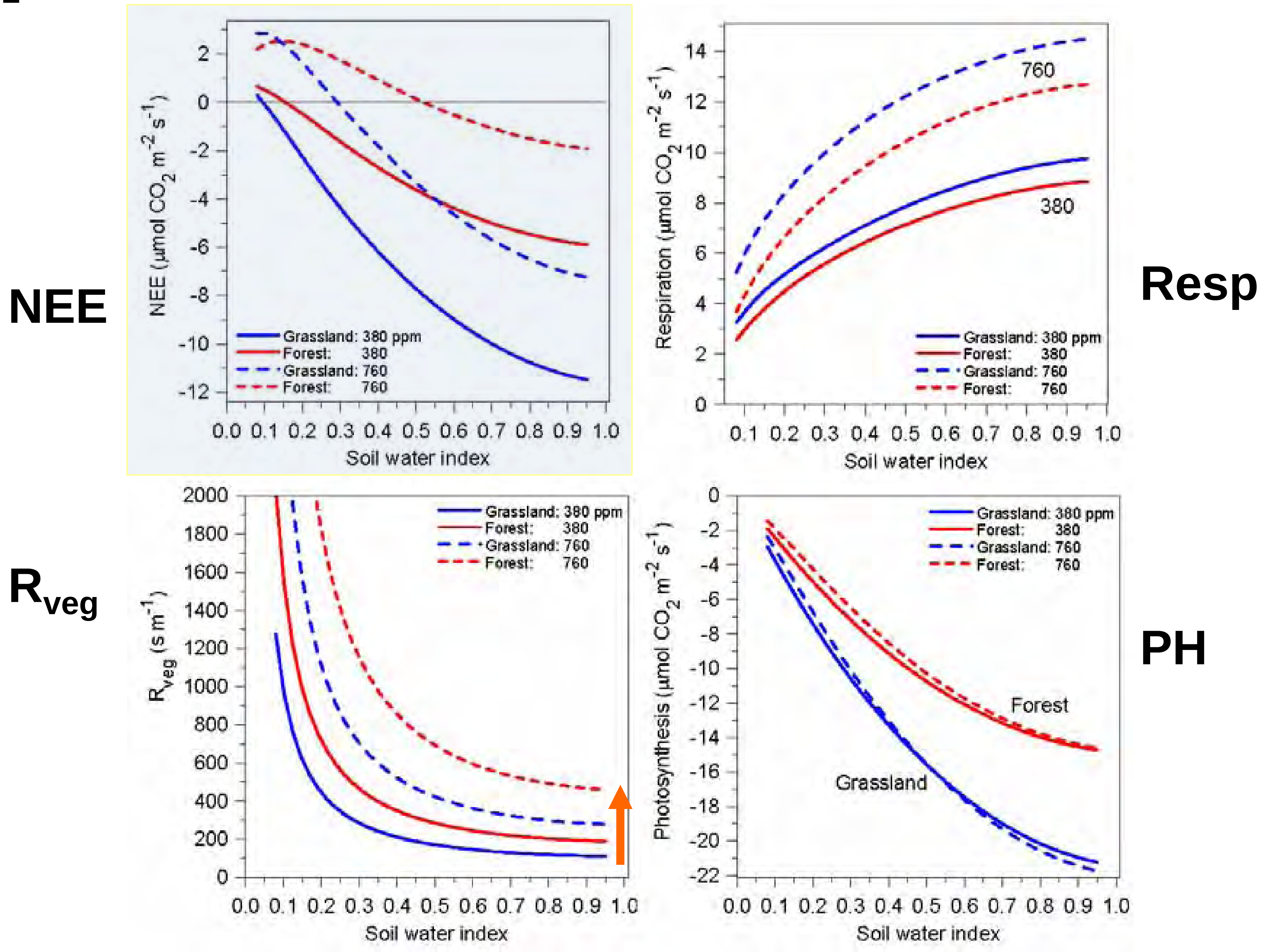




λE

Soil water index

CO_2 fluxes



Soil water index

Equilibrium model conclusions

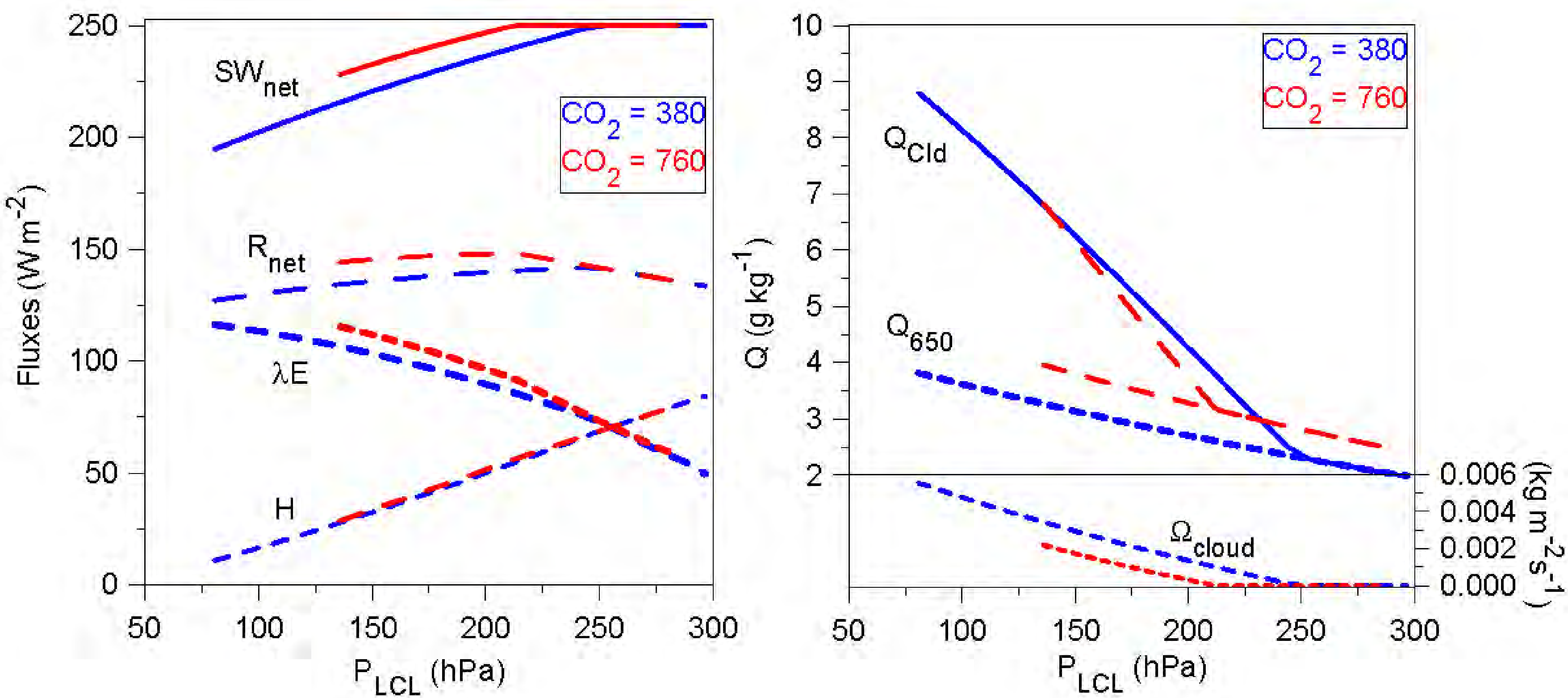
- Mid-lat. forest to grassland conversion **increases** BL cloud albedo (order +5%)
- Doubling CO_2 **reduces** transpiration, RH and BL cloud albedo (order -14%)
- This **amplifies surface warming over land** +2K over ocean to +4.8K [2-m]; +5.6K at land-surface
- Warming with double CO_2 reduces NEE. [Model forest loses carbon for SWI<0.5]
- If forest to grassland conversion; 2-m land warming drops to 3K *[Caveats: same soil-water; subsidence]*

Conclusions

- **Simplified model shows large changes in BL-cloud over land with vegetation change and warmer high CO_2 climate**

- **GCM vegetation models should be tested offline in coupled BL mode to separate cloud forcing and carbon sink issues**

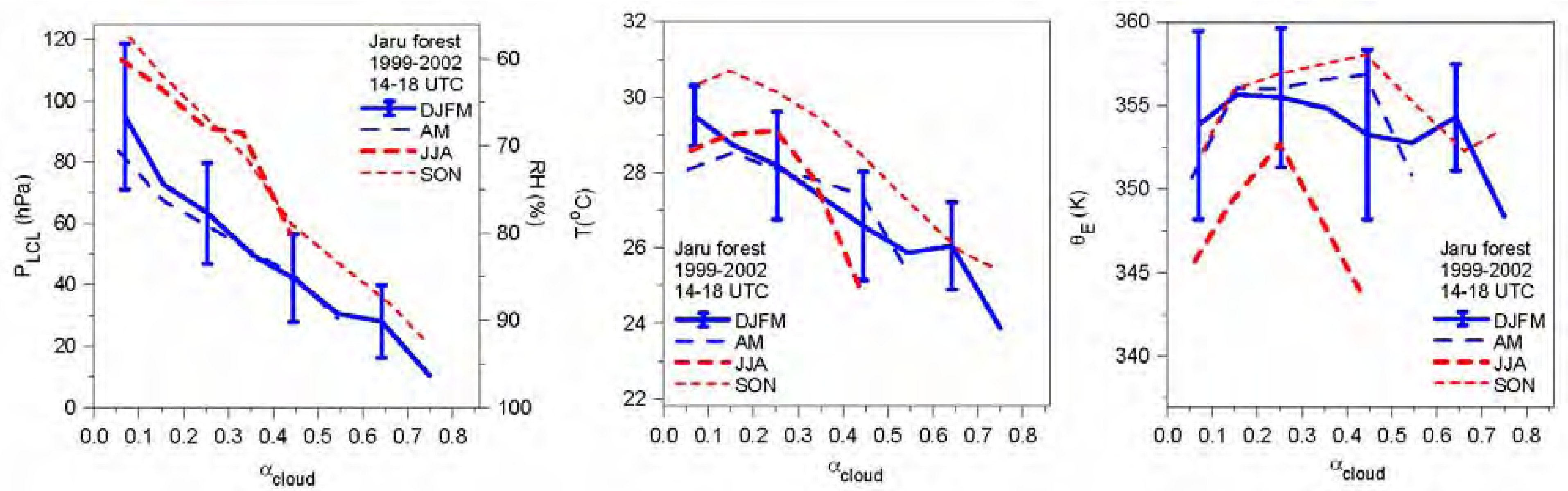
Fluxes, Q & clouds - P_{LCL}



- As cloud ⟶ 0, collapses to ML model
- Only clear-sky LW coupling left

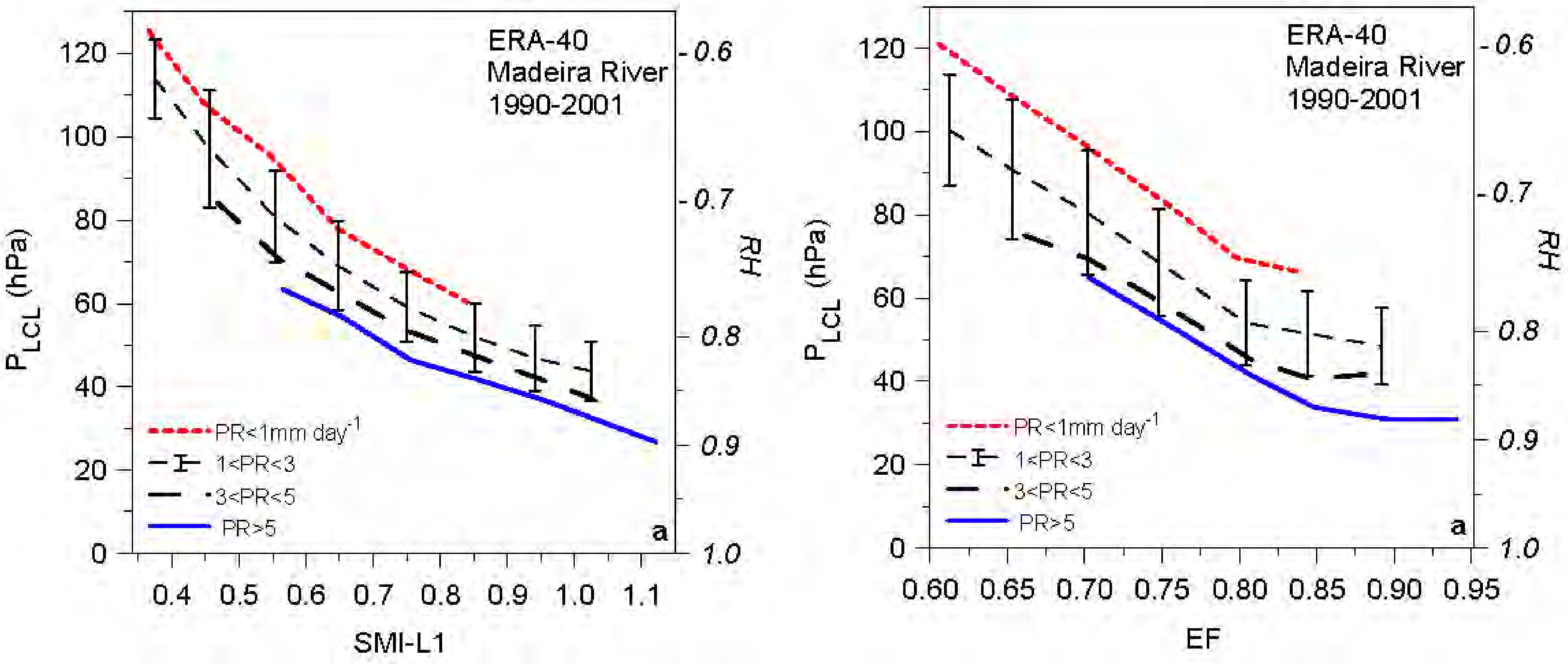
Cloud - BL coupling

Jaru forest – Noon ±2h



- Cloud amount coupled to cloud-base & RH
- Temperature decreases as cloud increases
- θ_E is flat: regulated by cloud transports

Land-surface-BL Coupling



- SMI-L1 = (SM- 0.171)/(0.323-0.171) ***(soil moisture index)***
- P_{LCL} stratified by Precip. & SMI-L1 or EF
- Highly coupled system: only P_{LCL} *observable: Mixed layer depth*